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A simple method for estimating phytoplankton abundance using a surface seawater monitoring system off Syowa Station during austral summer

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Abstract: A surface seawater monitoring system was used aboard the *Shirase* to estimate phytoplankton abundance while the icebreaker was anchored in an ice covered area off Syowa Station during the austral summer of 1996/97. A significant positive relationship was observed between the digital output (OP) values of the chlorophyll fluorometer of the system, and chlorophyll *a* (Chl *a*) concentrations of the seawater that passed through the system. Using this relationship, OP values were converted into Chl *a* (Chl *a* OP). Throughout the present study, the Chl *a* OP was found to be consistent with temporal changes in Chl *a* observed in the field near the *Shirase*, with high Chl *a* OP values measured in relatively warm and less saline water. These findings suggest that the high Chl *a* may be derived from the ice-edge phytoplankton blooms that develop in stable waters associated with melting ice. Relatively simple operation without need for complicated maintenance procedures facilitates the ease with which the system can be used. The operation of the system every summer may facilitate the acquisition of data that reveal the long-term variability of phytoplankton biomass under fast ice.

key words: Lützow-Holm Bay, chlorophyll fluorometer, simple operation

Introduction

Syowa Station (69˚00´S, 39˚35´E) is located in Lützow-Holm Bay, an area that is often inaccessible because of heavy sea ice. However, compared to the early half of the 1990s, sea ice breakup now frequently occurs in the bay (Ushio, 2003). The distribution of sea ice off Lützow-Holm Bay is thought to affect, not only phytoplankton distribution under the fast ice near Syowa Station (Odate, unpublished data), but also reproduction in the Adélie penguin (Kato *et al*., 2002). In the event that global warming reduces sea ice extent, it must also affect the ecosystems of the Antarctic coastal zone. Consequently, long-term monitoring of biological processes is necessary in order to evaluate the impact of global warming on sea ice ecosystems.

Several studies have demonstrated the temporal variation of phytoplankton abundance that occurs beneath fast ice near Syowa Station (Hoshiai, 1969; Fukuchi *et al*., 1984; Satoh *et al*., 1986, 1991; Matsuda *et al*., 1987; Odate and Fukuchi, 1996; Ishikawa *et al*., 2001). However, due primarily to lack of manpower, few programs have been designed for long-term monitoring in this region.

A surface seawater monitoring system capable of recording water temperature, salinity and phytoplankton abundance has been installed on board the icebreaker *Shirase* (Fukuchi and Hattori, 1987). This system has been used to assess the spatial distribution of phytoplankton abundance and water masses along cruise tracks of *Shirase* in the Southern Ocean (Odate and Fukuchi, 1995). The purpose of the present study was to determine whether the surface seawater monitoring system could be used to detect temporal variations in phytoplankton abundance under fast ice. The study was undertaken when the *Shirase* was anchored in an ice-covered area off Syowa Station during austral summer.

Materials and methods

Temporal changes in phytoplankton abundance were monitored at one-minute intervals using the surface seawater monitoring system (Fukuchi and Hattori, 1987) installed onboard the icebreaker *Shirase* while she was anchored off Syowa Station during the 38th Japanese Antarctic Research Expedition (Fig. 1). The seawater intake was located at the bottom of the ship (about 8 m below the sea surface). The system consists of a CTD (OS200, Ocean

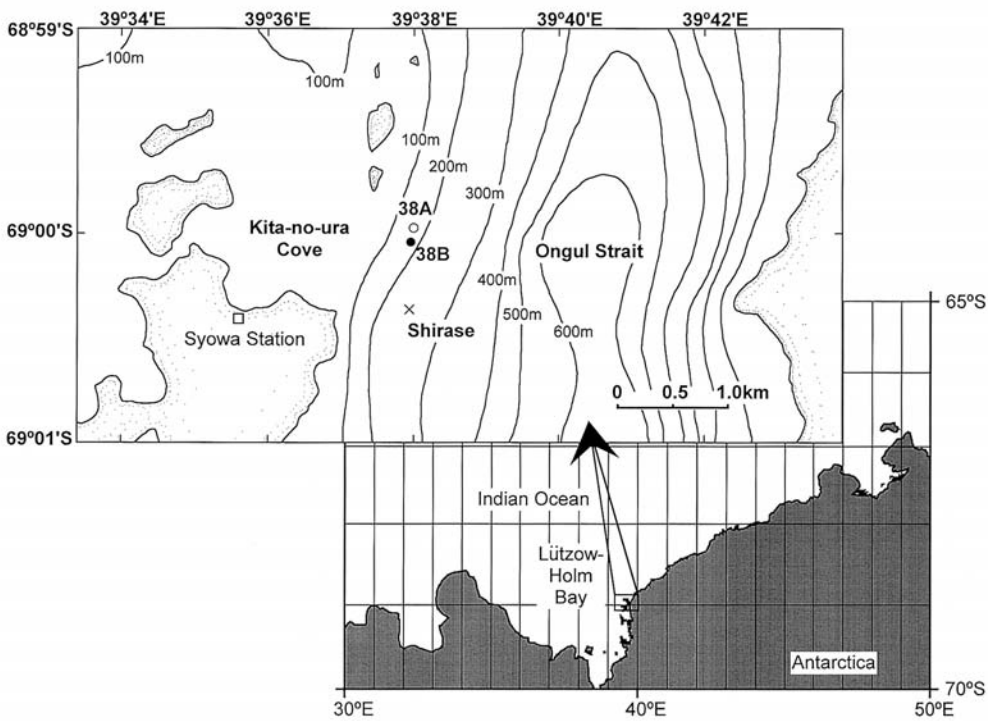

Fig. 1. The icebreaker *Shirase* was anchored from 27 December 1996 to 22 January 1997 off Syowa Station (cross). Field observations were conducted at Sites 38A and 38B (Odate, unpublished data). Submarine topography (depth in m) has been redrawn after Fujiwara (1971).

Sensors, Inc., San Diego, CA USA) for the measurement of temperature and salinity, and a chlorophyll fluorometer (WETStar, WETLabs Inc., Philomath, OR USA) for the measurement of phytoplankton concentration. The main specifications of the fluorometer were, optical sensitivity: 0.03 μg l^{-1}, wavelength excitation: 470 nm, and wavelength emission: 685 nm. Seawater was supplied to the sensor unit at approximately 1.5 liters per minute. The sensors and sample lines of the system were cleaned previous to the present study and no maintenance was undertaken over the observation period. In the present study, observations were made from 0000 LT on 2 January to 0000 LT on 20 January 1997.

In order to ensure the accuracy of the digital readings for chlorophyll *a* concentration obtained using the surface seawater monitoring system, direct measurements of chlorophyll *a* (Chl *a*) concentrations were made from seawater samples passing through the system. From January 2 to 18, 1997, 31 seawater samples were collected from a drain of the surface seawater monitoring system. 18 and 13 samples were collected during the day (0600–1800 LT) and night (1800–0600 LT), respectively. Seawater samples (100 or 200 m*l*) were filtered directly through a glass microfiber filter (Grade GF/F, Whatman International Ltd., Kent, UK), which retains fine particles down to 0.7 μm. Each filter was immediately placed in an opaque glass vial containing N,N-dimethylformamide (Wako Pure Chemical Industries Ltd., Osaka, Japan) (Suzuki and Ishimaru, 1990) and Chl *a* concentrations were determined using a fluorometer (Model 10-000 R Fluorometer, Turner Designs Inc., Sunnyvale, CA USA) (Parsons *et al*., 1984) after 24 hours. The fluorometer was calibrated with pure Chl *a* (Sigma Chemical Co., St. Louis, MO USA).

Chl *a* concentrations estimated by the surface seawater monitoring system were compared with field observations under fast ice at Sites 38A and 38B (Fig. 1). Seawater samples were collected using a Niskin bottle from a depth of 5 m below the ocean surface and Chl *a* concentrations were determined using the same methods described above (Odate, unpublished data). The sea ice thickness was 2–2.5 m around the observation area.

Results and discussion

Output values (OP) obtained from the chlorophyll fluorometer of the surface seawater monitoring system varied between 0.10 and 4.2 from 0000 LT on January 2 to 0000 LT on January 20, 1997. There was a significant relationship between OP values and Chl *a* concentrations of the seawater that passed through the system (Fig. 2).

$$\text{Chl } a = 5.7\text{OP}^{0.81} \quad (n=31,\ r^2=0.92,\ P<0.01).$$

Using the equation above, OP values were converted into Chl *a* concentrations (Chl *a* OP). A running mean for two hours was adopted for the Chl *a* OP (solid line in Fig. 3). Figure 3 also depicts temporal changes in Chl *a* concentration observed at 5 m depth at Sites 38A and 38B (open and closed circles in Fig. 3, respectively; Odate, unpublished data), (Chl *a* Field). The Chl *a* OP varied approximately 1–2 μg l^{-1} between 1 to 5 January, during which the Chl *a* Field was 1.5 μg l^{-1} at Site 38B (2 January) and 2.2 μg l^{-1} at Site 38A (3 January), but measured 3.6 μgl^{-1} at Site 38B (5 January). Chl *a* OP was observed to increase rapidly from 6 to 7 January. This rapid increase was not detected in the field because no field observation was made on 7 January. The Chl *a* OP decreased slightly with irregular fluctuations observed from 7 to 15 January. During this period, Chl *a* Field and Chl *a* OP were

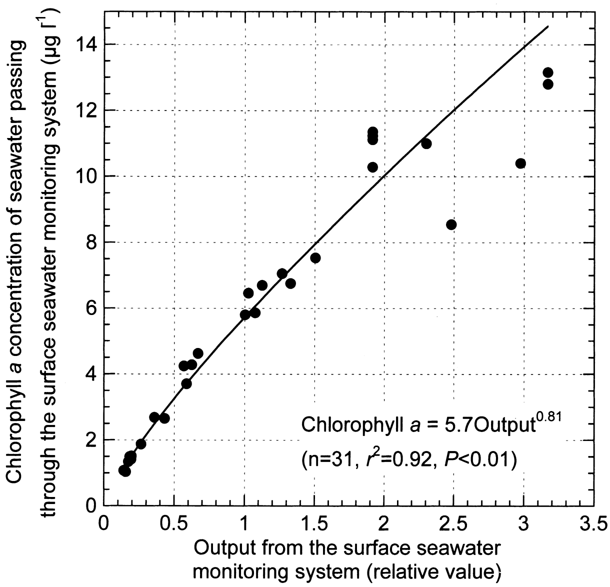

Fig. 2. Relationship between output values obtained using the surface seawater monitoring system and chlorophyll *a* concentration of seawater passing through the system.

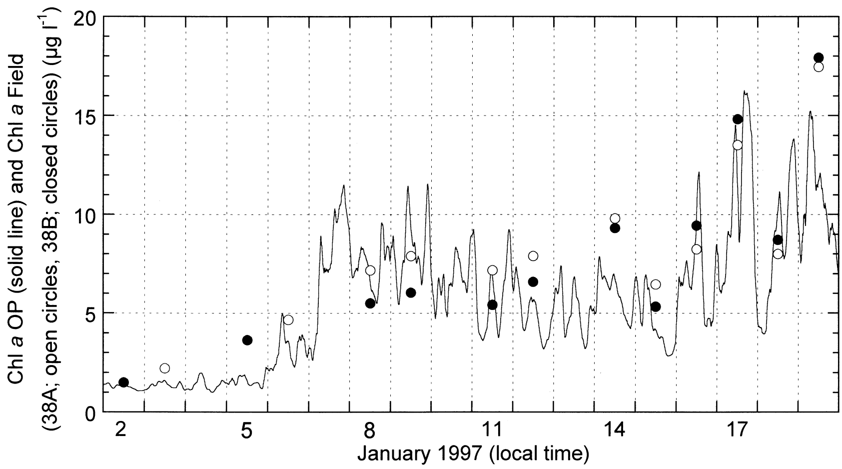

Fig. 3. Temporal change in chlorophyll *a* concentration estimated using the surface seawater monitoring system onboard the *Shirase*, from 2 to 19 January, 1997 (Chl *a* OP; solid line) (running mean for two hours). Field observations (Chl *a* Field) at Sites 38A (open circles) and 38B (closed circles) are also shown (Odate, unpublished data).

observed to be similar. However, the Chl *a* OP was *ca* 70% of the Chl *a* Field on 14 January. Chl *a* OP increased sharply from 15 to 17 January and decreased markedly on the night of 17 January. The increase observed from 15 to 17 January was detected by the field observation,

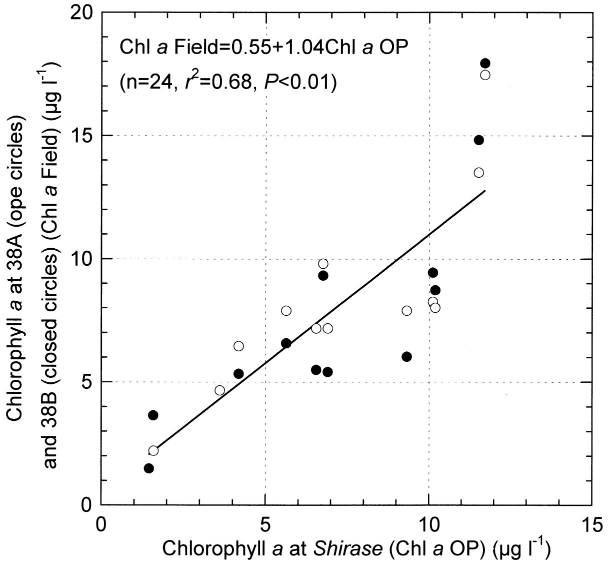

Fig. 4. Relationships between chlorophyll *a* concentrations observed aboard the *Shirase* using the surface seawater monitoring system (Chl *a* OP) against field observations (Chl *a* Field) at Sites 38A (open circles) and 38B (closed circles) (Odate, unpublished data).

with increases in Chl *a* OP observed again from the early morning of 17 January to the morning of 19 January.

Throughout the present study, Chl *a* OP was observed to be very consistent with the Chl *a* Field (Fig. 4). During the summer of 1996/97, phytoplankton biomass was uniformly distributed under fast ice near Syowa Station (Odate, unpublished data). This could account for the similar levels and temporal patterns in Chl *a* concentrations at Sites 38A and 38B and aboard the *Shirase*. In this summer, the Chl *a* Field values were observed to have increased further by the end of January (Odate, unpublished data), but no Chl *a* OP data became available after the icebreaker *Shirase* departed from Syowa Station on 22 January. However, given the consistency between Chl *a* OP and Chl *a* Field measurements obtained by 19 January, it is likely that Chl *a* OP would have been higher if the observations had continued.

It has been shown that a large increase of Chl *a* concentration occurs in $<$10 m depth below the ocean surface during mid-late January (Odate and Fukuchi, 1996). Thus, the intake of seawater at a depth of approximately 8 m below the ocean surface should be appropriate to detect temporal variations in Chl *a* during summer.

In the case of fluorescence determination *in vivo*, high values have often been observed at night (Odate *et al.*, 2000). No such trend was observed to occur during the present study. This may have resulted from extreme darkness under fast ice (Odate *et al.*, 2004).

Figure 5 shows Chl *a* OP plotted against the temperature and salinity data obtained in the present study (25920 data points). The plots show that high Chl *a* OP values are obtained in relatively warm and less saline water. This suggests that one of the possible factors of the high Chl *a* concentrations is advection of seawater from the ice-edge, where phytoplankton blooms occur in water made highly stable by the melting ice (Smith and Nelson, 1985).

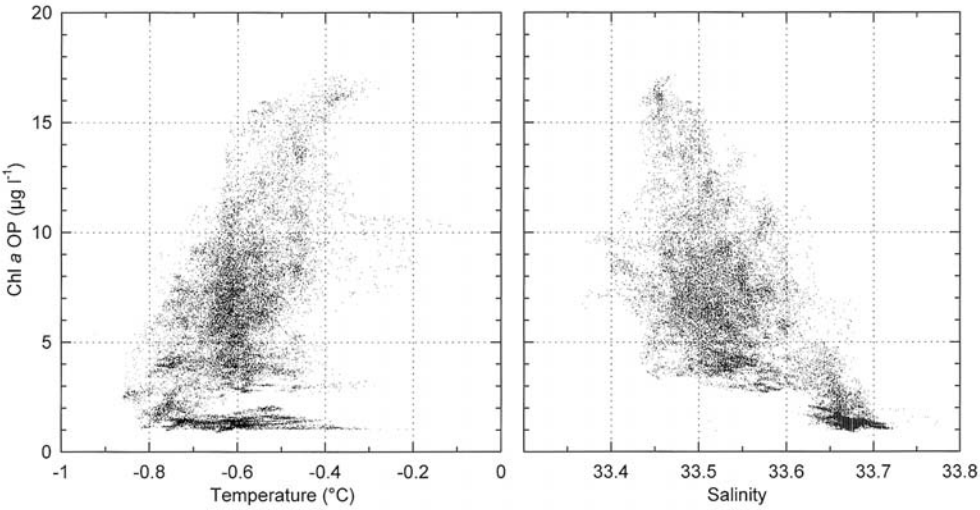

Fig. 5. Relationships between chlorophyll *a* concentrations observed aboard the *Shirase* using the surface seawater monitoring system (Chl *a* OP) against temperature (left) and salinity (right).

Recently, a decrease in salinity has been observed in Lützow-Holm Bay (Aoki, personal communication). Since changes in water column properties are likely to affect biological processes under fast ice, long-term monitoring is required to assess the dynamics of water properties and biological parameters.

The present observations, taken using the surface seawater monitoring system, showed that rapid Chl *a* fluctuations in occurred frequently, sometimes even within a day (Fig. 3). The fluctuations seem to result from movement of seawater. It is difficult to detect such rapid variations using field observations in practice since the temporal resolution for such observations is once a day. The surface seawater monitoring system is a powerful tool with which rapid changes in Chl *a* concentration can be observed with a high degree of temporal resolution under the fast ice near Syowa Station in summer. The primary, and most important, merit of the surface seawater monitoring system is its ease of operation without the need for complicated maintenance. This allows all members of an expedition to operate the system. The operation of the surface seawater monitoring system off Syowa Station every summer may facilitate the acquisition of data that reveal the long-term variability of phytoplankton biomass under fast ice.

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